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Development of Turbulent Biological Closure Parameterizations

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LONG-TERM GOAL

The long-term goal of this project is to understand and represent the dynamical role of planktonic fluctuations induced by physical turbulence. Additionally, this work is intended to be the basis of an efficient representation and methodology which will allow their inclusion in real ocean mean field dynamical models.

OBJECTIVES

I.   Extend Goodman and Robinson (2007) statistically based theory to include a greater variety of fundamental biophysical dynamical processes;
II.   Development of turbulent subgrid scale parameterizations for non linear biophysical interaction;
III.   Application of the PDF theory and the parameterized Advective Diffusive Reaction (ADR) model to oceanographically relevant processes.

APPROACH AND CONTEXT

A nonlinear model for biological and physical dynamical interactions in a laminar upwelling flow field Robinson(1999) has been extended to turbulent flow (Goodman and Robinson, 2007). Lagrangian and Eulerian probability density functions have been derived and applied to obtain the statistics of the biological state variables and mean dynamical effects of fluctuation correlations. This approach has been shown to lead to closed form solutions for the ensemble averaged biological state variables; no additional assumption is required to close the biodynamical interaction terms. The nonlinear uptake of Nutrient (N) by Phytoplankton (P) in a linear strain upwelling field and random walk turbulence has been explored in detail. It has been shown that the mean P, N fields can be obtained in terms of α, the ratio of mean advection to rate of uptake of nutrients, and Pe, (Peclet number), the ratio of time scale of turbulent diffusion to that of mean advection. The mean net primary production was found to be equal in the laminar limit of $Pe = \infty$ and strong turbulence limit of $Pe = 0$. For the advection parameter α = .1, characteristic of a typical ocean near surface layer, mean net primary production was found to exhibit a maximum at some intermediate value of Pe. The mean total production <PN> is composed of two terms, <P> <N> and <P'N'> which are opposite in sign resulting in <PN> being much smaller than each of the two contributing terms.

WORK COMPLETED

Many fundamental biological dynamical processes in the sea are strongly non-linear. Thus, physical turbulence in the sea not only enhances advective transport processes by eddy diffusivity but also importantly induces turbulent fluctuations in biological state variables which can correlate in the mean and effect mean biological dynamics. Goodman and Robinson (Proc. Roy. Soc A, 2008, <u>484</u>, 555-572; doi: 10.1098/rspa. 2007.0251) have formulated a theory of turbulent biological-physical interactions in terms of probability density functions (pdfs) and applied it to the simple example of nutrient (N) and seed phytoplankton (P) upwelling into a surface turbulent layer. The mean uptake <PN> is the sum of the product of the means <P><N> and the often neglected correlation fluctuations <P'N'>. <PN> and <P><N> are positive, but <P'N'> is found to be negative and to significantly reduce <PN>. We have parameterized <P'N'> by <P><N> with a proportionality constant a function of two non-dimensional parameters: i) the ratio of the biological uptake time scale to the upwelling time, α, and ii) the ratio of the upwelling time scale to the turbulent diffusive time, Pe, (Peclet number).

In the figure below for the steady state the integrated phytoplankton in the near surface layer is plotted versus Pe for different values of α. The integrated phytoplankton density is nearly independent of Pe. However note that there is a maximum at $Pe \approx 5$ for $\alpha = .1$. An ADR (advective-diffusive-reactive) model has been formulated for the mean fields <P>, <N> and solved analytically for the intense turbulent limit of small Peclet number. It is found that for Pe = 0, the fully turbulent case, <P> is constant. In the table below are shown results comparing the parameter $C = <P>_{Pe=0}$ for the pdf and ADR theories. Agreement of <P>, <N> values in the mixed layer between the two theories is excellent. The ADR results provide useful insight into coupled turbulent physical-biological dynamical processes.

Integrated Phytoplankton and Production versus Pe

2
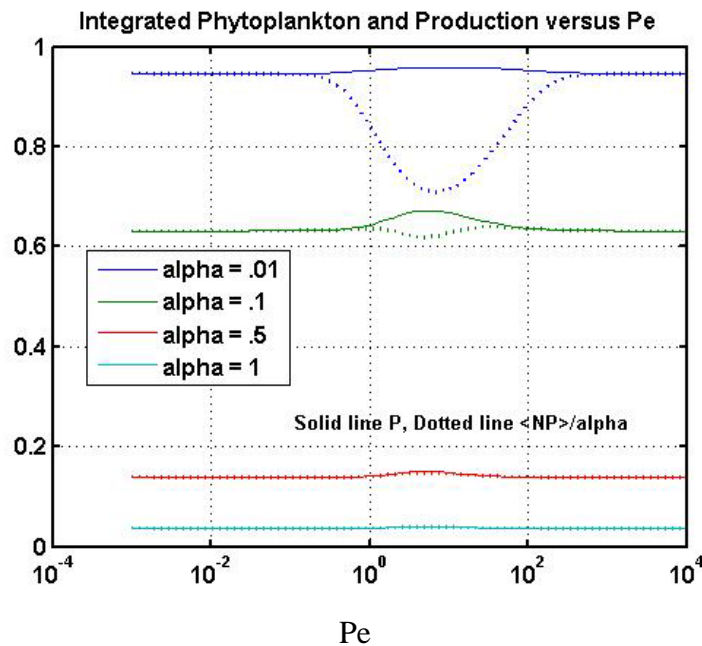
Table

	α	.01	.05	.1	.25	.5
PDF Theory	C	.96	.80	.63	.35	.15
ADR Model	C	.96	.81	.64	.29	.19

IMPACT/APPLICATIONS

The often neglected turblence induced correlated fluctuations of biological and biophysical fields should be able to be explcitly included in biodynamical proceses. This in turn will allow the inclusion of important biological and biophyscial processes in interdisciplinary predictive environmental models. It is expected that this work will contibute significantly to the new subfield of biogeophysical fluid dynamics.

REFERENCES

Robinson, A.R. 1999 On the theory of Advective effects on biological dynamics in the sea, II Localization, Light limitation, and nutrient saturation, *Proc R. Soc. London A*., **455**, 1813-1828.

Goodman and Robinson, *Proc R Soc A* (2008) 469, 555-572.